Pleistocene-Recent Boundary in the Rocky Mountain Region

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By CHARLES B. HUNT

A CONTRIBUTION TO GENERAL GEOLOGY

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Stratigraphy and paleontology of alluvial, cave, and lake deposits of late Quaternary age

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By Charles B. Hunt

ABSTRACT

The disappearance from the Rocky Mountain region of certain Pleistocene mammals, such as the elephants and camels, coincides with a widespread unconformity in the late Quaternary deposits of the region. The deposits overlying the unconformity contain a modern fauna, including species like *Bison bison* that do not occur in the older deposits. Also, the deposits above and below the unconformity are distinct lithologically. It is proposed that this stratigraphic break be designated the boundary between the Pleistocene and Recent in this region. The break is marked by desiccation of the great Pleistocene lakes, arroyo cutting in valleys that had been aggraded with Pleistocene alluvium, cessation of solution or other spring action in caves, development of extensive sand dunes, and disappearance of glaciers in the mountains.

INTRODUCTION

Stratigraphic studies of late Quaternary deposits in the Rocky Mountain region reveal a widespread uncomformity separating deposits that differ lithologically and that contain rather different faunas. The deposits below the unconformity contain the remains of certain Pleistocene mammals, such as the elephants, American mastodon, camels, sloth, peccary (*Platygonus*), *Cervalces*, *Bison antiquus*, the northern Pleistocene bison (*B. occidentalis*), the woodland musk ox (*Symbos*), the giant beaver (*Castoroides*), and other genera. The deposits overlying the unconformity contain a modern fauna, including species like *Bison bison* that do not occur in the older deposits. In the Rocky Mountain region this unconformity is a convenient boundary between the Pleistocene and Recent.

The break in sedimentation represented by the unconformity apparently marks the major climatic change that followed the last glacial maximum. The latest deposits containing Pleistocene fossils record moist conditions. For example: In basins they include lacus-

trine sediments; along valleys they include fill terraces; and in caves they include stalagmite and related deposits. However, the earliest overlying deposits, the Recent deposits, contain a modern fauna and record arid conditions: at old lake sites they include eolian or fluviatile sediments that overlap the earlier lacustrine sediments; along stream valleys they are represented by alluvium or gravel that mantles cut terraces or fills channels cut into the earlier deposits; in caves they are represented by dust.

Although the stratigraphy clearly indicates many climatic fluctuations during the late Pleistocene and Recent, it is equally clear that the late Pleistocene deposits do not record conditions as arid as during the dry stages of the Recent, nor do the latter deposits record a return to conditions as moist as those indicated by the late Pleistocene deposits. Moreover, the disappearance of so many mammals at the end of the Pleistocene, whether by extermination or by migration away from the region, seems to be surprisingly complete. If some of these mammals did linger into the early Recent at least their numbers in this region were reduced virtually to the point of extermination so that the fauna of the late Pleistocene deposits is different from that of the Recent deposits.

The climatic change recorded by the early Recent deposits has been widely recognized, not only in this region but elsewhere in North America and in Europe; however, the kind and degree of the climatic change is still subject to considerable differences of opinion. Leopold (1951), for example, has recently pointed out some of the difficulties in estimating the relative effects of changes in precipitation as against changes in temperature.

Various terms have been proposed for the early part of the Recent, but all have been based upon interpretations of the climate (for example, postglacial climatic optimum, postglacial warm period, period of great aridity, altithermal). These interpretive terms are useful for discussing history, but stratigraphic nomenclature should be based upon the physical geology and paleontology of the deposits themselves and not upon the history they seem to record. It is frequently difficult enough to ascertain the stratigraphic position of a deposit; we compound our difficulties if we use a nomenclature based upon second-order interpretations.

Much more study of the Recent deposits in the Rocky Mountain region is needed before we can develop a satisfactory nomenclature for them. The studies made thus far indicate that the Recent deposits commonly have an orderly fivefold arrangement. The earliest consist of sand dunes; where these are absent there is an erosional unconformity. In either case an arid environment is indicated. The remainder of the Recent deposits includes at least two alluvial or lacustrine formations, each of which was followed by a period of erosion.

The alluvial or lacustrine deposits seem to record moist stages; the periods of erosion seem to record moderately dry stages.

At many places the Recent deposits of different ages can be distinguished on the basis of their archeologic remains. Pottery, for example, was introduced in this region about the beginning of the Christian Era and provides a convenient means for separating earlier and younger deposits. It seems likely that the sequence of cultural occupations that have been recognized, in part at least, probably correlate with and reflect the sequence of changes in the physical environment.

STRATIGRAPHY

ALLUVIAL DEPOSITS

The alluvial deposits in the Rock Mountain region that contain remains of the Pleistocene mammals generally are thicker, more clayey, and more compact than the younger alluvial deposits that contain a modern fauna. In places these Pleistocene alluvial deposits are correlative with glacial outwash.

The late Pleistocene and the Recent alluvial deposits seem to have been deposited under substantially different conditions of stream regimen. Both on the High Plains and on the Colorado Plateaus the late Pleistocene alluvium commonly is homogeneous in composition and texture longitudinally along the main streams, and the flood plain surface on this alluvium is nearly a plane. On the other hand, the Recent alluvium in the main valleys is composed of broad low coalescing fans that apex in the tributaries. Its flood-plain surfaces in general are rolling, and the composition and texture of the alluvium may vary considerably from the mouth of one tributary to another. One gets the impression that the flow in the main streams relative to that in the tributaries was greater during Pleistocene time than during the Recent.

The arroyo cutting that terminated deposition of the Pleistocene alluvium, in general, was deeper and more extensive than the arroyo cutting that alternated with the deposition of the Recent alluvial deposits.

The Recent alluvium generally can be separated into older and younger deposits on the basis of superposition of beds. Archeologically the older alluvium is pre-pottery in age; the younger alluvium, which was deposited during the Christian Era, commonly contains pottery. The Pleistocene alluvial deposits locally contain stone artifacts.

Stratigraphic sections illustrating these general relationships have been reported in the Navajo country and Whitewater Creek, Ariz.; in the Trans-Pecos Region, Tex.; the Cerro Pedernal area, New Mexico; and in the Denver area, Colorado.

NAVAJO COUNTRY, ARIZONA

In the western Navajo country, in northeast Arizona, Hack (1942) recognized the following sequence:

Late Quaternary deposition and erosion in the western Navajo country

[After Hack 1942]

Present-day arroyo cutting.
Deposition of alluvial Naha formation (post A. D. 1300).
Arroyo cutting (ca. A. D. 1300).
Deposition of alluvial Tsegi formation.
Arroyo cutting and development of dunes.
Deposition of alluvial Jeddito formation; elephant bones; no artifacts.

The period of arroyo cutting and dune development that followed deposition of the Jeddito formation, according to Hack (1942, p. 69) "is the driest period recorded by the deposits of the western Navaho country. It is therefore most likely to be correlated with the postglacial optimum * * *."

The alluvial Tsegi formation was deposited before the area was occupied by the pottery-using Pueblo peoples.

In the western Navajo country the proposed boundary between the Pleistocene and Recent would be at the top of the Jeddito formation.

WHITEWATER CREEK, ARIZ.

The archeology and geology of the Whitewater Creek area in southeastern Arizona have been studied by Sayles and Antevs (1941). The following is a generalized composite section of the stratigraphy they reported:

Generalized composite section of deposits along Whitewater Creek, Ariz.

[After Sayles and Antevs, 1941]

	Average thickness (feet)
Surface.	
1. Silt or sandy silt, laminated, cream-colored; upper part contains bones of domestic cow and horse	2.0
Erosional unconformity; pottery occurs at the unconformity; erosion ca. A. D. 1300.	
2. Clay, massive, brown, and silt; probably a mixture of soil and alluvial deposits such as occur on wet meadows; locally very laminated and similar to bed 3. Local erosional unconformities occur within the unit. Mammal bones of modern type. Pottery only in the uppermost layers; lower layers contain stone artifacts of the San Pedro and Chiracahua stages	3.0
Erosional unconformity.	
3. Clay, laminated, varved (?). Probably deposited in beaver ponds. Contains bones of fish and of mammoth; stone artifacts of Sulphur Spring stage	4.0
4. Sand and gravel. Contains bones of extinct horse, camel, pronghorn antelope, dire wolf; charcoal of hickory; stone artifacts of Sulphur Spring stage	5.0
Base.	

As pointed out by Antevs (Sayles and Antevs, 1941, p. 48), beds 3 and 4 provide evidence of perennial ponds and streams. Bed 3 contains fish bones in addition to having what seems to be annular laminations. Bed 4 contains hickory which does not now occur closer than eastern Texas. These beds also contain the remains of several mammals that are extinct. Beds 3 and 4 record a period more moist than the present, and indeed more moist than is indicated by any of the younger beds. They probably correlate with the deposits of Lake Cochise to the north, which also have yielded remains of elephant, camel, and extinct horse (Bryan and Gidley, 1926, p. 477–488; Sayles and Antevs, 1941, p. 38).

The massive clay, bed 2, has been interpreted by Antevs (Sayles and Antevs, p. 35) as having been deposited in a cienaga, or wet meadow, a condition more moist than the present but less moist than is indicated by beds 3 and 4. Bed 2 contains mammal bones of modern type and most of the bed is pre-pottery in age.

The proposed boundary between the Pleistocene and Recent would be at the unconformity between beds 2 and 3. Apparently this unconformity spans one or more of the dry stages that occurred at the beginning of the Recent because bed 2, which is the earliest Recent deposit, indicates a moderately moist environment.

TRANS-PECOS REGION, TEX.

In parts of the Trans-Pecos Region, Tex., Albritton and Bryan (1939) and Kelley, Campbell, and Lehmer (1940) found the following sequence:

Deposition and erosion in Alpine area, Texas

[After Albritton and Bryan, 1939, and Kelley, Campbell, and Lehmer 1940]

Modern arroyo cutting.

Alluvial Kokernot formation; deposition began probably before A. D. 1400 and perhaps as early as A. D. 1100. Contains pottery.

Arroyo cutting; probably started as early as A. D. 900 but perhaps not until A. D. 1100.

Alluvial Calamity formation; contains local unconformities, a modern fauna, stone artifacts, no pottery.

Arroyo cutting; at this unconformity occur stone artifacts, no pottery.

Alluvial Neville formation; contains bones of mammoth and extinct horse and bison; no known human occupation.

The Neville formation records a period of aggradation, apparently a moist period, contemporaneous with the mammoth and extinct forms of the horse and bison. The post-Neville erosion, apparently a dry period, was more extensive than the post-Calamity or post-Kokernot erosion. The post-Neville erosion was followed by

deposition of the Calamity formation, an alluvial deposit that is less extensive than the Neville. It contains a modern fauna and stone artifacts but no pottery.

The proposed Pleistocene-Recent boundary would be at the unconformity between the Neville and Calamity formations. This unconformity spans the dry period or periods at the beginning of the Recent because the Calamity formation represents moderately moist conditions.

CERRO PEDERNAL AREA, NEW MEXICO

Along the Rito de los Encinos, in the Cerro Pedernal area of north-central New Mexico, Bryan (1939) found an alluvial sequence that is very similar to, although somewhat less complete than, the sequences in the western Navajo country and Trans-Pecos Region. He reported the following:

Sequence of deposition and erosion along the Rito de los Encinos

[After Bryan, 1939]

Modern arroyo cutting, 1885 or later.

Late alluvium, loose and friable; contains charcoal hearths and many flint chips; probably of Puebloan age although no pottery was found in it.

Arroyo cutting.

Intermediate alluvium; less compact than the early alluvium and contains more humus; gravelly beds cemented by lime carbonate; stone artifacts, no pottery. No bones reported but Bryan (1939, p. 38) correlates this deposit with other alluvium containing a modern fauna.

Arroyo cutting.

Early alluvium; more reddish, and more firm and compact than the later alluvial deposits. Contains fragment of proboscidian tusk; no trace of human occupation.

According to Bryan (1939, p. 14) the dissection following the deposition of the early alluvium was severe and perhaps prolonged because the alluvium was almost entirely removed from a large part of the valley. However, the gully formed by the dissection of the intermediate alluvium was smaller in size and little larger than the present arroyo (Bryan, p. 14).

The early alluvium can be interpreted as the deposit of a moist period at a time when the mammoth, or other proboscidea, were extant in the Cerro Pedernal area. The erosion that followed was more severe than any later erosion and probably represents the arid period or periods in the early Recent. The proposed boundary between the Pleistocene and Recent therefore would be at the top of the early alluvium.

DENVER AREA, COLORADO

Geologic mapping of the Quaternary deposits in several 7½-minute quadrangles in the Denver area, Colorado, reveals a late Pleistocene and Recent history like the history of the areas already described (Hunt, 1953).

The following is a generalized section of the deposits in the Denver area:

1. Alluvium, contains pottery. Probably deposited during the second millennium of the Christian Era.

Unconformity, represented by arroyo cutting.

2. Alluvium, thicker and more extensive than unit 1. Numerous stone artifacts, no pottery; abundant *Bison bison*.

Unconformity; represented in the valleys by arroyo cutting; represented on the uplands by eolian deposits.

3. Gravel and sand deposits in main valleys, at least 60 feet thick; alluvium in tributaries; eolian deposits on uplands. Abundant remains of mammoth, camel, musk ox, and horse. Uppermost beds contain split bone, believed to have been artificially split.

The gravel and sand (unit 3) were deposited by melt water from the glaciers in the Front Range. They correlate with the gravel fill at Dent, Colo., where Clovis fluted projectile points have been found associated with articulated mammoth remains (Wormington, 1949, p. 38).

The next younger alluvial deposits, unit 2, occur as a shallow alluvial fill within the valleys. This alluvium contains a modern fauna; it is pre-Woodland culture in age, that is, pre-pottery. It was followed in turn by a period of arroyo cutting and a still younger and apparently only slightly prehistoric alluvium.

The paleontology of the Denver area provides some interesting statistics about the disappearance of the Pleistocene mammals. One hundred and five mammalian bones have been collected in this area. Seventy of the specimens were from the Pleistocene beds, and 51 of these 70 were identified as camel, mammoth, musk ox, *Bison occidentalis*, extinct horse, or other animals that do not occur in the Recent deposits. With one possible exception, the 35 specimens collected from the Recent deposits do not include any of the distinctly Pleistocene forms. The one exception is a lower jaw of a *Bison* which, because of its large size, may be *B. occidentalis*. It was collected from unit 2, whereas elsewhere this species was found only in unit 3.

Even assuming this jawbone does record *B. occidentalis* surviving into the Recent, the statistics of the collections indicate that 98 percent of that part of the fauna represented by the half dozen Pleistocene species disappeared from this region before the earliest Recent deposits were formed. Also the jawbone could be an oversize *B.*

bison, or it could have been reworked from Pleistocene alluvium nearby, which contains abundant *B. occidentalis*. If so, the disappearance of the half dozen Pleistocene mammals was 100 percent complete before the earliest Recent deposits were formed in this region. In any case the faunal change is sufficient to be referred to as a paleontologic discontinuity.

In the Denver area the fluvial and eolian deposits represented by unit 3 in the section contain remains of extinct animals; these deposits are Pleistocene. An erosional unconformity, probably recording a dry period or periods, separates these deposits from younger alluvium which is pre-pottery in age but which contains a modern fauna. The boundary between the Pleistocene and Recent should be at the top of unit 3.

CAVE DEPOSITS

Numerous caves in the Rocky Mountain region have yielded bones of the Pleistocene mammals. The layers that have yielded these bones are the deepest in the caves, and the sediments composing them in general seem to have been water-laid. The overlying layers are composed mostly of loose dust and show little or no signs of water action. The upper layers contain a modern fauna and the artifacts of Recent cultures. These general relationship are illustrated by the stratigraphic sections that have been reported at Sandia Cave and Carlsbad, N. Mex.; Ventana Cave, Ariz.; and Gypsum Cave, Nev.

SANDIA CAVE, N. MEX.

Sandia Cave, which is in limestone in the north part of the Sandia Mountains, N. Mex., is notable archeologically because it has yielded stone artifacts of pre-Folsom age. It is also notable palenotologically because of the possibility that the ground sloth here survived until very recently. The archeologic study was conducted by Hibben (1941). Bryan (1941 a, p. 45–64), who studied the geologic stratigraphy, gives the following section and interpretation of the deposits:

Deposits of Sandia Cave

[After Bryan, 1941a, p. 48–49]

Top.

1. Dust guano, and trash; 6 feet thick near the mouth but thins inward. Contains bones of modern fauna except ground sloth which occurs in lower part. Contains pottery of early Spanish or immediately pre-Spanish date (A. D. 1400–1600).
2. Stalagmite layer: 6 inches to paper thinness; granular and crystalline texture; in places "chalky"; the surface marked by a few Tivoli-type cups. Contains a few stones and in places is broken by falls of blocks from the roof.

3. Cave breccia, upper: 1 to 4 feet thick; consists of fragments of limestone, rounded and irregular masses of yellow ochre. Fauna includes horse, camel, bison, mammoth, ground sloth, and wolf. Folsom-type artifacts.
4. Ochre, yellow: 2 inches to 2 feet thick; uniformly fine-grained yellow ochre (limonite) banded and laminated; a few thin layers of chalky granular calcium carbonate. No fossil bone, artifacts, or limestone fragments.
5. Cave breccia, lower: As much as 3 feet thick; fragments of limestone, rounded and irregular fragments of limonite especially near top; cementation, by granular calcium carbonate, firmer at and near top. Fauna includes horse, bison, camel, mastodon, and mammoth. Sandia-type projectile points and other stone artifacts.
6. Clay: As much as 2 feet thick; gray; contains fragments of limestone showing solution surfaces; loose crinoid stems; occurs mostly in depressions of the floor. No human occupation.

Base.

The lower cave breccia (unit 5) and the upper cave breccia (unit 3) are interpreted by Bryan (1941a, p. 49) as having accumulated while the cave entrance was open, and while considerable quantities of water were dripping from the roof. Inasmuch as the yellow ochre layer (unit 4) is free of fossil bone and artifacts, Bryan infers that the entrance must have been closed or the drip from the roof was so severe that the cave was uninhabitable. But, he states, "The factor of closure seems inadequate to explain the almost exclusive deposition of ochre and a strong drip, and therefore moister conditions are implied."

Because the supply of refuse ceased when the upper cave breccia had been deposited, it is inferred that the entrance became closed or inaccessible to man and animals. Drip from the roof deposited the stalagmite layer (unit 2), but the drip gradually ceased. The archeologic record indicates that the cave was unoccupied for a long period after the stalagmite layer had been formed; presumably the cave was both closed and dry during this period. It was not reoccupied until about A. D. 1400.

Numerous bones of ground sloth were found at the base of the topmost layer (unit 1). However, it seems to me very unlikely that the sloth survived into the second millennium of the Christian Era as recent deposits earlier than the top layer in Sandia Cave have been studied in many places in the Rocky Mountain region, but they have not yielded sloth remains. Considering the regional evidence, it seems likely that the sloth bones are at least as old as the stalagmite layer and that they have been reworked into the younger beds by rodents or man.

The stalagmite layer and all the older ones indicate moist conditions, and clearly these conditions prevailed while many of the distinctly Pleistocene animals were still living in this part of New Mexico. The stalagmite layer and all the earlier deposits therefore could be classed as Pleistocene. The cessation of the accumulation of sediments recorded by the unconformity at the top of the stalagmite layer apparently indicates much drier conditions, although the unconformity must represent all but the last few hundred years of Recent time.

CARLSBAD, N. MEX.

A stratigraphy similar to that at Sandia Cave has been reported in a cave on the eastern slopes of the Guadalupe Mountains about 50 miles west of Carlsbad. Mason (1932, p. 499) described it as follows:

> The principal cave * * * was extremely dry and contained eight feet of dust and debris. Typical artifacts of early Basket Maker culture were encountered on the surface and to a depth of 20 inches below it. * * * Beneath this, to a total depth of 7 feet, were found hearths, artifacts, and bones of extinct animals. Among the latter were species of bison, antelope, horse, camel, musk-ox, and California condor. * * * Associated with bones of an extinct species of bison, at a depth of about 4 feet beneath the lowest Basket Maker burial, was found a hearth and a spear point of Folsom culture type; a musk-ox horn was found at a slight distance away on the same level. The paleontological remains, especially those of the musk-ox, indicate very definitely that the climate of this region at that time was considerably more humid and colder than at present and suggest an approach to glacial conditions.

Although the foregoing description is not sufficiently complete to identify contacts, evidently the upper beds are Recent and the lower beds are Pleistocene.

VENTANA CAVE, ARIZ.

Ventana Cave, located in the central part of the Papago Indian Reservation in southern Arizona, is in andesitic lava. The archeology of the cave was studied by Haury and the geology by Bryan (Haury, 1950). The following is a generalized stratigraphic section of the cave deposits:

Deposits at Ventana Cave

[After Bryan, 1950]

Top.	*Maximum thickness (feet)*
1. Dust and camp refuse, dry; contains pottery	3.0
2. Dust and camp refuse, moist; bones of modern animals; pottery only at absolute top; stone artifacts of Chiricahua and San Pedro stages of the Chochise culture	8.0
3. Talus cone, uncemented; few artifacts; bones of modern animals	1.8
Erosional disconformity.	
4. Sand, wind-blown; partly cemented with calcium carbonate	0.8

	Maximum thickness (feet)
Distinct erosional unconformity.	
5. a. Calcium carbonate, granular, in irregular plates, separated by thin films of uncemented sand	0.5
b. Sand, pulverulent, tuffaceous, silty, with high lime content. Bones of extinct horse, jaguar, sloth, four-horned antelope, and tapir. Projectile point of Folsom aspect	1.0
6. Gravel, minutely bedded, fine, over angular coarse gravel and silt; lime cemented. Bones of tapir, dire wolf, extinct horse, and four-pronged antelope	5.6
Base.	

Bryan (1950, p. 87) inferred that bed 6 was deposited when the spring in the cave had a greater flow than at present and therefore when there was greater rainfall and presumably also less evaporation than at present. Bed 5 probably represents a period when the flow had diminished. According to Bryan the erosional unconformity at the top of bed 5 represents an "interval when removal of material from the cave exceeded deposition. Such conditions are compatible with a much drier climate, one even drier than the present."

The upper beds (1 to 4) were deposited when the flow of the spring was low. As stated by Bryan (1950, p. 87) "the partly cemented beds 3 and 4 seem to be the work of flood and wind, and the presence of calcareous cement may indicate slightly humid conditions. Beds 1 and 2 appear to be largely man-induced—they testify to relatively dry conditions."

The stratigraphy of these cave deposits records a change from moist to dry conditions, and the final disappearance of the Pleistocene mammals coincides with that change. Also, here as in other parts of the West, Folsom-type artifacts are associated with the extinct mammals. And bed 3 and all but the top of bed 2 record a pre-pottery occupation at a time when conditions were more moist than now but not so moist as when the Pleistocene mammals were extant.

The proposed boundary between the Pleistocene and Recent would be at the top of bed 5.

GYPSUM CAVE, NEV.

Gypsum Cave, located about 20 miles northeast of Las Vegas, Nev., is a solution cavern in Paleozoic limestone, although it was named for the selenite crystals that it contains. The stratigraphy of Gypsum Cave is similar to that of Sandia Cave. The upper layers contain a modern fauna and artifacts of a pottery culture. The deeper layers contain remains of extinct animals and artifacts of a lithic culture. Harrington (1933) studied the archeology of the cave; Stock (1931) studied the paleontology. The following is a generalized stratigraphic section of the cave deposits:

Stratigraphic section of deposits in Gypsum Cave

[Generalized, after Harrington, 1933, and Stock, 1931]

Top.	*Feet*
1. Dust, ashes, loose stones; contains mountain-sheep dung, corn cobs, pottery, and other Puebloan artifacts	2
2. Earth, hard, brown; lenticular and discontinuous; contains mountain-sheep dung, occasional stone artifacts	1
3. Limestone, broken; contains very little extraneous material, probably a catastrophic rockfall	3
4. Earth, brown, and mountain-sheep dung	3
5. Dust and gravel, occasional larger rocks, gray gypsum streaks of partly consolidated gypsum, local stalagmite at top. Contains mountain-sheep dung, bones and dung of sloth, bones of camel and horse, stone and wood artifacts	2–7
Base.	

According to Harrington (1933, p. 166–167) the deposits represented by the lower part of unit 5 were laid down by running water, which had sufficient force to transport small rock fragments from the higher parts of the cave. The upper part of unit 5, including the sloth-bearing layers, and units 1 to 4 were deposited without the aid of running water. They are composed of poorly sorted coarse and fine materials. On page 167 Harrington states:

when the layers containing the ground-sloth remains were forming, some parts of the cave were still damp enough to permit the formation of stalagmites by water-drip from the roof. This is shown by the fact that one sloth skeleton had been partly covered by the "apron" of a stalagmite and this part was badly disentegrated from dampness; while a little farther away from the stalagmite the cave floor was so dry that the hair and horny claws of, apparently, the same individual sloth, as well as the bones, were preserved.[1] In these "sloth-bearing" layers were evidently represented a period when the climate was dryer than the preceding, but less arid than the present, because no stalagmites are being formed now.

A study of the deposits resting on the sloth layers (units 1 to 4) indicates no return of a wet climate between the day of the sloth and our own time—in fact these strata record no geological events of consequence except the extinction of sloth, horses, and camels, and a single earthquake violent enough to bring down large masses or rock from the roof of the cavern (unit 3).

Stating the whole case in a few words: The strata in Gypsum Cave indicate first a very rainy period with abundant running surface water, followed by a time of increasing dryness, terminating in the exceedingly arid conditions we find today. Very important is the fact that the deposits containing the ground-sloth, with associated camels, horses, and man, were laid down when desiccation was quite well advanced, but before aridity had reached its present state.

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[1] These finely preserved sloth remains of demonstrable great antiquity help to explain other similarly well-preserved but otherwise undated remains in the Rocky Mountain region (see, for example, Lull, 1929, p. 4, 5).

Study of the plant materials in the sloth dung indicates that the Joshua tree (*Yucca brevifolia*) was a favorite food of the sloth. This tree no longer grows about Gypsum Cave (altitude 2,000 feet) but thrives at higher altitudes, above 3,000 feet. Some of the wooden artifacts associated with the sloth remains are species of elder and buckthorn that grow only at higher altitudes at the present time (Harrington, 1933, p. 193, 194).

The boundary between the Pleistocene and Recent in the Gypsum Cave deposits should be drawn at the top of unit 5.

LAKE DEPOSITS

The deposits that accumulated in the large Pleistocene lakes in the Basin and Range province are thick and extensive, and they contain the remains of Pleistocene mammals. From the preserved shorelines it is evident that these old lakes stood at a higher level than any of the succeeding ones. Overlying the Pleistocene lake beds are the Recent eolian sand, fluvial deposits, or thin lake beds. The Recent deposits contain the remains of a modern fauna.

A similar stratigraphy but on a much smaller scale is found at various places on the High Plains.

These general relationships are illustrated by the stratigraphic sections that have been reported in the Great Basin at Lake Lahontan, Lake Bonneville, and Summer Lake, and in the High Plains at Clovis and San Jon, N. Mex. Additional localities on the High Plains have been described by Sellards (1952).

LAKE LAHONTAN, NEV.

In the upper lacustrine clays of Lake Lahontan, Russell (1885, p. 143) found the remains of horse, camel and mastodon or elephant. Jones (1925, p. 49) added to this fauna by finding a species of lion, *Felix atrox;* a species of horse related to either *Equus pacificus* or *E. occidentalis;* and a camel near *Camelops.* A spearhead in Walker River Canyon was found "associated in such manner with the bones of an elephant, or mastodon, as to leave no doubt as to their having been buried at approximately the same time. Both are genuine fossils of the upper Lahontan period" (Russell, 1885, p. 247). The upper Lahontan period, as that term was used by Russell, refers to the last high-level stage of Lake Lahontan. Following this high stage the lake became desiccated. "The water continued to fall until the basin was completely dry" (Russell, p. 252). The dry period that followed the moist Lake Lahontan period was described by Russell (p. 268) as "a period of great aridity." Subsequently the climate moderated and small lakes formed at various places in the Lake Lahontan basin.

This sequence in the Lake Lahontan basin is closely parallel to the events already described. Man and animals that are now extinct in the region coinhabited this area during a moist period that favored huge lakes. This period was followed by one of great aridity, which in turn was followed by a succession of alternating moderately moist and moderately dry periods. The lack of erosion of the Lake Lahontan beach lines led Jones (1925, p. 50) to the opinion that "the history of Lake Lahontan has all taken place within the past few thousand years." This interpretation of course would imply that the animals are recently extinct. The prevailing opinion, however (see, for example, Antevs, 1925, p. 75–76; 1944), would assign the last high-level stage of the lake to the late Pleistocene. The deposits formed during the period or periods of great aridity to which Russel referred and during the subsequent moderately moist and moderately dry periods should be classed as Recent.

LAKE BONNEVILLE, UTAH

The physical geology of Lake Bonneville records a history like that of Lake Lahontan. The last high-level stage of that lake is the Provo shoreline. Subsequently the lake level dropped at least as low as the Stansbury shoreline, and perhaps even lower because that shoreline may represent a later, comparatively minor and short-lived rise of the lake.

There has never been much question about the Pleistocene age of Lake Bonneville including the Provo stage. In the post-Provo stages as the lake shrank the basin became divided into a number of minor hydrographic units. Gilbert (1890, p. 260) wrote, "This modern epoch may be called the post-Bonneville epoch of low water." Thus he clearly set the post-Provo stages apart from the earlier ones. In the nomenclature of this paper the post-Provo stages represent the Recent.

There is very little paleontologic evidence from the Bonneville basin that bears on the problem of distinguishing between Pleistocene and Recent deposits. Romer (1928) has described a camel skull which he believed to be post-Bonneville in age.

> The specimen was discovered by two high-school boys of Fillmore, Utah, who, at the time, were exploring the igneous buttes of some twenty miles south and west of that village. It was found about two hundred feet back in a cave, buried under about three or four feet of fine dry eolian deposit, which was easy to excavate. The cave is one of the many caverns formed in the old lava beds of the district, which, according to Gilbert (1890, p. 329–332), are post-Bonneville in age.

The exact locality is not given but the reference to Gilbert identifies it as lying within the Tabernacle crater and lava field. These lava beds are younger than the Bonneville shoreline but they were contemporaneous with the Provo. Gilbert (1890, p. 331) described the age of the crater and lavas as follows:

the lava field must have been formed after the fall of the water from the Bonneville level to the Provo. Bearing the Provo shore mark, it must have been spread before the close of the Provo epoch. It therefore originated during the Provo epoch. * * * The outer rim (of the crater) * * * belongs to the Bonneville shore epoch or to the earlier part of the Provo epoch.

Part of the eruptive rocks are pre-Provo in age; part are Provo in age. The camel is younger than these eruptive rocks, but beyond that there is no stratigraphic evidence as to its age. It could be late Pleistocene as are all the other occurrences of the camel that have been described and dated stratigraphically in the region.

The freshness of the tissues that were found still adhering to the skull has also been cited as evidence of the recency of the camel (Romer, 1928, p. 20). But the sloth remains in the deposits at Gypsum Cave (see p. 12) show that tissues of late Pleistocene age can be preserved in dry caves.

There is, on the other hand, some evidence that the Bonneville basin fauna became modern in type after the lake had receded below the level of the Stansbury shoreline. Around Great Salt Lake numerous caves have been excavated for archeologic remains. Prehistoric people occupied these caves shortly after the lake waters dropped below the Stansbury level (Steward, 1937, p. 103, 119–120). Abundant vertebrate remains have been collected in the caves—as many as 150 specimens from a single cave—but they include only modern forms (Steward, 1937, p. 81–82, 102, 118). With so much material it is surprising not to find some remains of the Pleistocene mammals unless indeed their numbers in this area had become reduced virtually to the point of extermination.

SUMMER LAKE, OREG.

At the Summer Lake area in south-central Oregon are lake deposits that record a late Pleistocene and Recent history much like that of the Lake Lahontan and Lake Bonneville basins (Allison, 1945, p. 789–808). The deposits of Winter Lake, the name applied to the last high-level lake in the Summer Lake basin, have been correlated with those of the Provo stage of Lake Bonneville and with those of the upper Lahontan period of Lake Lahontan (Allison 1945, p. 801).

In the upper part of the sediments of the Winter Lake stage are beds of volcanic ash including some that are correlated with and attributed to the climactic eruptions of Mount Mazama, the eruptions that led to the formation of Crater Lake (Allison 1945, p. 797). In caves in the hills overlooking the lake basin the same ash occurs above beds containing remains of camel, horse, and other animals that are not found in younger deposits (Allison, 1945, p. 804; Williams, 1942, p. 115). Artifacts also have been found beneath these ash beds (Cressman and Williams, 1940, p. 53–78).

These deposits record a moist period at a time when the vertebrate fauna included species that no longer survive in the region. In the nomenclature of this paper the deposits should be classed as Pleistocene; because the deposits contain artifacts, they are probably late Pleistocene in age. The younger deposits in the Summer Lake basin record arid conditions; they have not yielded remains of extinct animals. In the nomenclature of this paper these are the Recent deposits.

CLOVIS, N. MEX.

In the Quaternary lake beds between Clovis and Portales, N. Mex., Clovis fluted projectile points are associated with remains of mammoth, camel, and extinct bison and horse. When the area was occupied, there was sufficient moisture to form lakes in what is now a dry part of the plains (Howard, 1935; Antevs, 1935; Lohman, 1935; Stock and Bode, 1936; Cotter 1937, 1938; Antevs 1949, p. 185–189).

The deposit from which the Clovis fluted points and extinct mammals were obtained was laid down in a shallow lake basin, which indicates a climate more moist than that prevailing today in this part of New Mexico. Subsequently, wind erosion of the lake beds produced small basins bordered, mostly on the northeast side, by sand dunes and silt (Stocks and Bode, 1936, p. 240; Antevs 1949, p. 186).

The physical geology records a change from moist to dry conditions, and, if this were the only evidence available, we could not be sure how recently the change occurred. However, the paleontologic and archeologic evidence combined with that from physical geology provides reasonable assurance that the lake beds are of Pleistocene age and that the overlying dune sand, which lacks the Pleistocene mammals and Clovis fluted points, was deposited during the Recent.

In northeastern Colorado as in the Clovis–Portales area, good evidence has been found of the former existence of perennial lakes whose deposits have been subjected to wind erosion and are overlain by dune sand (Gebhard, 1949). Folsom- and Yuma-type points and remains of mammoth reportedly have been found in the lake beds, but the kind of excavation necessary to establish the association and stratigraphy has not been undertaken (Gebhard, p. 134). The overlying dune sand has yielded artifacts that are non-Folsom and non-Yuma in type; these are associated with *Bison bison* (Gebhard, p. 135), which indicates a Recent age.

SAN JON, N. MEX.

Depressions in the plains near San Jon, N. Mex., contain lake or pond deposits. These are unconformably overlain by alluvial deposits that form terraces and record periods of aridity alternating

with periods somewhat more moist than the present. The lake or pond deposits contain San Jon projectile points and remains of proboscidea, and of a large bison, possibly *Bison taylori*. The alluvial deposits contain Scottsbluff points, formerly classed as Yuma points, and *B. bison* (Judson, 1950; Roberts, 1942; Wormington, 1949). The following section illustrates the stratigraphy at San Jon.

Beds exposed at San Jon, N. Mex.

[Summarized after Judson, 1950, p. 263]

	Feet
1. Modern deposits in the arroyos	0–10
Disconformity.	
2. Alluvial gravel, sand, and silt; forms low terrace with base 1 to 5 feet above arroyo	5–15
Disconformity.	
3. Alluvial gravel, sand, and silt; forms intermediate terrace with base 8 to 10 feet above arroyo	5–15
Disconformity.	
4. Alluvial gravel, sand, and silt; forms high terrace with base 20 to 25 feet above arroyo. Contains bones of *Bison bison*	10–15
Disconformity.	
5. Alluvium, reddish to reddish-brown; alternating beds of sand and clayey-humic material. Contains numerous iron-manganese nodules averaging one-fourth inch in diameter. Lime occurs as tubules and as films along joints in the clayey horizons. Occurs in broad channels cut into underlying formations 40 to 50 feet above arroyos. Contains *Bison bison* and Scottsbluff points	0–50
Disconformity.	
6. Clay, dark blue-gray, grading laterally into greenish clay and into reddish compact sandy alluvium towards the borders of the basin. Contains nodules and plates of iron-manganese oxide and concretions and plates of calcite. Lime plates occur on laminations and on vertical joint planes. About 5 feet above base are lenses of volcanic ash. This unit apparently is a lake or pond deposit. Contains bones of proboscidea and of a large bison, possibly *B. taylori;* artifacts include San Jon projectile points	0–50
Disconformity.	
7. Basal sand. Upper columnar jointed zone has calcareous concretions, iron-manganese flecks, and clay-filled cracks	0–50
Base.	

Judson points out (1950, p. 261) that the deposits show—

that exterior drainage was developed before the site was occupied by the people who used the Eden Valley Yuma (Scottsbluff) projectile points and hunted the

modern species of bison. Furthermore, the depression was breached after the occupation of the site by those who hunted a giant and extinct bison and who fashioned the San Jon point at a time that may be equivalent with the true Folsom horizon.

The change in physical geology and the coincident change in fauna at the disconformity between units 5 and 6 in the section at San Jon parallel the sequence of events in other parts of the region. The disconformity is a logical boundary between the Pleistocene and Recent.

GLACIAL DEPOSITS

The climatic history recorded by the glaciers in the mountains of the western United States (Matthes, 1939, p. 519–520; 1940, p. 398–403) is similar to that recorded by the alluvial, cave, and lacustrine deposits. The last major glaciation in the mountains seems to have been followed by a period in which most of the glacial ice was melted. Subsequently, there were comparatively minor advances of the mountain glaciers that are analagous to and probably correlative with the development of small lakes in the Great Basin and alluviation in the valleys.

In the Rocky Mountain region the morainic deposits rarely contain fossils and only locally is it possible to correlate individual moraines with fossil-bearing outwash or lake beds; but the late Pleistocene and Recent glacial history of the region, so far as it is known, is compatible with the geologic history recorded by the stratigraphy of the alluvial, cave, and lacustrine deposits.

SUMMARY OF FIELD EVIDENCE AND PROPOSED DEFINITIONS

In the foregoing summary descriptions I have tried to select different kinds of areas having a fairly complete late Quaternary physical stratigraphy and, wherever possible, having supplementary paleontologic evidence. Numerous other areas in the Rocky Mountain region have been studied and some have been mapped, but, so far as I have been able to determine, they all show the same general sequence of events although in varying degrees of completeness.

The unity of pattern in the stratigraphy of the different kinds of late Quaternary deposits in the Rocky Mountain region provides an adequate basis for a reasonably satisfactory nomenclature, at least within the region. The correlations that are involved are those that have been generally accepted and the general history has already been pointed out by many others (see, for example: Bryan, 1940, p. 227–232; 1941b, p. 505–514; 1941c, p. 228–229; Antevs, 1948, p. 168–191). Moreover, this paper is by no means the first to propose

this definition for separating Pleistocene and Recent deposits in the region (see, for example, Krieger, 1948; Sellards, 1952, p. 5).

The stratigraphic record reveals a major change in sedimentation or erosion about the time when the distinctly Pleistocene mammals disappeared from the region. In most of the Rocky Mountain region this change in sedimentation is marked by an unconformity, and in addition the younger deposits are mappably different from the older. This change in sedimentary history evidently was caused by changes in climate, for the climate that induced the last major glaciation apparently was followed by one that was warmer and (or) drier than the present.

The change in climate apparently so changed the balance of nature as to cause the extermination or migration from the region of a dozen or more species of mammals. The stratigraphic record indicates that the elimination of the Pleistocene animals from the fauna occurred with surprising abruptness. The general impression that the Pleistocene animals survived well into the Recent is not supported by the field evidence available. Only at Sandia Cave (see p. 8) have bones of unequivocal Pleistocene animals been found in deposits that can be dated stratigraphically as Recent. Even this occurrence is equivocal in that there is a good chance that the sloth bones in the upper layers at Sandia Cave were reworked upwards by rodents or man.

The impression that the Pleistocene animals in the Rocky Mountain region survived into the Recent has been based partly on the freshness of tissue preserved with some of the specimens collected from caves (Lull, 1929; Romer, 1928). The inadequacy of this evidence is illustrated by the occurrence of sloth, already described, at Gypsum Cave (see p. 12) and by the fact that mummified amphibian tissue has been reported from formations as old as Oligocene (Zittel, 1923, p. 208–209). The argument for recency of the extinct animals in the Lahontan basin was based on a supposed Recent date for Lake Lahontan itself (Jones, 1925). The argument for recency of the camel skull found near Fillmore, Utah, as pointed out earlier (see p. 14), was based on a misunderstanding of the term "post-Bonneville."

In the Rocky Mountain region certainly scores and perhaps hundreds of specimens of the Pleistocene animals have been collected from deposits that, on the basis of physical geology, are assuredly late Pleistocene. Large numbers of collections have been made from Recent deposits, but thus far not one articulated skeleton of the extinct mammals has been reported from these deposits. The disappearance of so many species as abruptly and as completely as is indicated by the stratigraphic record is difficult to accept. However, even sup-

posing that some Pleistocene animals are to be found in the Recent deposits, sufficient collections have already been made to indicate that the numbers of these Pleistocene animals decreased so greatly as to constitute a change in fauna.

Changes in fauna coincident with changes in physical geology like those recorded in the Rocky Mountain region are widely recognized in the Great Plains too. Sellards (1952, p. 116) summarized the stratigraphic data for a large number of localities on the Plains and described the faunal change on the southern High Plains as follows:

> From the evidence now at hand one may infer that on the southern High Plains as the bison greatly increased in number, the elephant, horse, and camel decreased. This inference is supported by the observation that at localities affording evidence of great bison herds other species of large mammals, such as elephant, mastodon, camel, and horse, are scarce or wanting. Various species of bison had long been present on the plains. However, it seems probable that when the great herds of bison such as were associated with Folsom man became established, most other large grazing animals were driven through biological competition from the plains but continued in the mountains and probably in the Coastal Plains.

The late Quaternary stratigraphy in the Rocky Mountain region fits into the definitions of Pleistocene and Recent that Forbes and Lyell proposed a hundred years ago (see quotation in Wilmarth, 1925, p. 46–49). Their definitions were based upon physical and paleontologic differences between the deposits they classed as Pleistocene and those they classed as Recent. The same kind of differences have been found in the Rocky Mountain region.

Accordingly it is proposed that the boundary between the Pleistocene and Recent in the Rocky Mountain region be drawn at the unconformity or other stratigraphic change that seems to record the onset of arid conditions immediately following the last glacial maximum. The physical break in the sedimentary history is generally marked either by desiccation of the great Pleistocene lakes, by arroyo cutting in the valleys that had been aggraded with Pleistocene alluvium, by cessation of solution activity or spring action in caves, by development of sand dunes, and probably by the disappearance of mountain glaciers. Paleontologically the break is marked by the disappearance from the region of the Pleistocene mammals, and it will probably be found to coincide with a major migration of the vegetation zones and fresh-water invertebrate fauna eastward across the plains and upward onto the mountains. Archeologically the break seems to be marked by the termination of Folsom occupation.

THE PROBLEM OF CONTEMPORANEITY

The field evidence indicates that the same kind of events occurred in the same sequence and in about the same degree throughout the

Rocky Mountain region, but it does not necessarily follow that the events in different parts of the region were contemporaneous. The relationship of any mappable deposit or contact to time lines commonly is a matter of uncertainty and may be a major problem. The proposed boundary between the Pleistocene and Recent has the same uncertainties, no more and no less, as the boundary between any other two series. The Pleistocene and Recent boundary and the subdivisions of either the Pleistocene or Recent should be defined on the same basis as the rest of the stratigraphic column is defined, namely, on the basis of observable features of the deposits and with due consideration given to discontinuities in the physical geology that coincide or approximately coincide with paleontologic discontinuities. If our Pleistocene and Recent stratigraphy is built on this basis, the relationship of the deposits to time lines and the problems of contemporaneity will be solved in due time.

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